

REMARKS

Applicants have carefully considered the Examiner's remarks and have amended the claims to more clearly set forth the invention. Claim 1 has been amended and new claim 19 has been added by this Amendment D. Thus, claims 1-10 and 19 are now pending in the application. As explained in detail below, the pending claims are believed to be in condition for allowance.

Claims 1-6 and 9-10 stand rejected under 35 U.S.C. 103(a) as being unpatentable over Cope, U.S. Patent No. 3,761,692. The Examiner admits that the Cope reference fails to show every feature of the claimed invention, and asserts that the Cope system differs from the present invention only in that PID control is also performed by Cope on the pull rate. To remedy this deficiency, the Examiner notes that "maintain[ing] the pull rate specified by the diameter control algorithm reads on pulling at a target rate which substantially follows a set velocity profile because the average pull rate profile of Cope is determined by the upper and lower imposed limits thereon." (See Office action at pages 3 and 4).

Cope discloses a method of pulling a silicon crystal ingot with a Czochralski crystal puller in which various control algorithms are used during the crystal pulling process. Specifically, Cope uses a temperature control algorithm, a diameter control algorithm, and a melt level control algorithm for controlling the crystal pulling process. (See column 4, lines 20 - 25). As disclosed by Cope, the "diameter sensor 64 applies a signal through digital filter 89 to the diameter control algorithm 82," and "controller 65 maintain[s] a crystal pull rate specified by the diameter control algorithm." (Column 5, lines 1-11). In other words, the pull rate of Cope is determined as a function of a diameter error sensed during the pulling process. Further in support of this reading, Cope discloses that the function of the diameter control algorithm is to *calculate* a new set point for the pull motor, using PID control (see column 17, lines 54-57). In particular, Cope teaches that the pull motor set point is calculated from the following equation:

$$\text{SAVE2} = \text{DIAER} + \text{DRPE} + 2(\text{DDERR}).$$

In this instance, Cope defines DIAER as the diameter integral error summation, which is determined as a function of the output of the diameter sensor averaging filter. (See FIG. 3 and column 18, lines 1-29).

With respect to power, Cope states that "the temperature control algorithm 81 receives a filtered input signal from the melt temperature sensor which *senses the temperature* of the molten silicon. The output of the temperature control algorithm is coupled to supply a set point to RF controller 62, which controls the RF generator 33, and the RF generator 33 is electrically coupled to the RF induction coils 37 to heat the silicon 49. (See column 3, lines 57-60, and column 4, lines 57-68). In other words, the Cope system controls pull rate as a function of diameter error and controls power as a function of measured melt temperature.

In contrast, the present invention relates to an improved method for controlling silicon crystal diameter in a *locked* seed growth process in which the pull rate is not affected or determined by changes in process conditions (e.g., diameter changes). In particular, applicants claim pulling the crystal from the melt according to a velocity profile. In other words, the targeted pull rate of applicants' invention exactly tracks the velocity profile. Of course, those skilled in the art will understand that the actual pull rate may vary from the target within operational tolerances, but the target is "locked" to the velocity profile. The Examiner's determination that the diameter control algorithm reads on pulling the crystal from the melt according to a velocity profile fails to appreciate the difference between active velocity control as disclosed by Cope and target velocity control as disclosed by applicants. According to applicants' invention, it is unnecessary to adjust the pull rate in response to changing in diameter (i.e., diameter error) because the velocity profile stored in a memory defines a target pull rate as a function of crystal length. (See application page 14, lines 10-12).

Another distinction between the present invention and the cited art is that rather than adjusting the power supplied to the heater as a function of a sensed temperature to control

diameter, applicants employ a temperature model to adjust the power being supplied to the heater as a function of diameter error in order to control diameter. Specifically, applicants disclose "that a PID control loop 265 receives *an error signal representing the difference between the crystal diameter set point and the crystal diameter process variable*. In turn, the PID loop 265 outputs a temperature set point at line 269. According to the invention, the control loop 261 includes a temperature model 273, which receives the temperature set point and outputs a heater power supply set point at line 275 to effect desired changes in the crystal diameter." (See application, page 20, lines 15-20). As known to those skilled in the art, temperature sensors are often blocked from the melt surface by, for example, the growing crystal or additional hot zone parts in the crystal growing apparatus. As such, temperature sensors are not necessarily reliable for measuring melt temperature during growth. For this reason, applicants' invention provides a significant improvement over the prior art.

To this end, independent claim 1 now recites, in part, "determining a power set point for the power supplied to the heater from the temperature model as a function of the error signal and *independent of a measured temperature*." Claim 1 also recites "pulling the ingot from the melt at a pull rate following a target pull rate defined by a velocity profile, said velocity profile being stored in memory and defining the target pull rate *independent of the error signal*." Neither the Cope patent nor the Araki patent make any mention whatsoever of determining a power set point independent of a measured temperature and/or determining a crystal pull rate without sensing diameter. Thus, applicants submit that claim 1 is allowable over the cited art.

Although the Examiner is correct that the pull rate is initially set to something (See Office action at page 6), the significant and relevant distinctions between the cited art and the present invention relate to how pull rate and heater power are determined *throughout* the crystal pulling process. Unlike the cited art, the present invention determines pull rate independent of changes in diameter, and determines heater power independent of a sensed temperature. The Examiner has improperly equated a normal operating range of pull rates with a profile that specifically defines the pull rate based on a target rate that exactly follows the profile.

Moreover, the Examiner maintains that no limitation is given by Cope that upper and lower limits of pull rate are prohibited from being set to the same value "x." (See Office action at pages 5 and 6). Again, the Examiner has improperly equated an acceptable operating range in the Cope patent to applicants' profile. In contrast to the Examiner's contention, Cope discloses that upper limit (DIAUL) and lower limit (DIALL) are determined from the following equations:

$$\text{DIAUL} = \text{VCN}(1 + \text{KR});$$

$$\text{DIALL} = \text{VCN}(1 - \text{KR});$$

where VCN is the average pull rate, and KR is an empirically derived fixed constant equal to 0.6. Thus, DIALL and DIAUL as defined by Cope are in fact not the same value. (See column 16, lines 55-65). Nevertheless, the appropriate inquiry for obviousness is not what the cited art does not teach, but rather whether the cited art teaches or suggests the invention as claimed. (See MPEP 2143.01 (explaining that the prior art must suggest the desirability of the claimed invention)).

Although there is some expected minimal tolerance in the pull rate even when the target exactly follows a predetermined velocity profile, as taught by applicants, a much smaller variation of pull rate is achieved (e.g., 10% of $|T|$, where $T = .055$) with the present invention. (See Application page 12, lines 20-22). In particular, applicants have discovered that "pulling crystal 31 according to velocity profile 159 produces silicon with a *nearly perfect crystalline structure and having very few intrinsic point defects*." (Application page 14, lines 11-14). This is yet another example of the significant benefits provided by the claimed invention.

For these reasons, applicants submit that claim 1 is allowable over the cited art. Claims 2-10 depend from claim 1 and are believed to be allowable for at least the same reasons as claim 1.

In addition, claim 19 depends from claim 1, and recites "performing proportional-integral-derivative (PID) control on the error signal and generating a temperature set point as a function thereof, and wherein the power set point for the power supplied to the heater is

determined from the temperature model as a function of the temperature set point generated by the PID control."

In view of the foregoing, applicants submit that the prior art references in no way teach or suggest each and every feature of the claimed invention, particularly, pulling a crystal at a target pull rate defined by a velocity profile, and independent of a diameter error, and determining a power set point for the power supplied to the heater from the temperature model as a function of the error signal and independent of a measured temperature. Applicants' invention enables accurate diameter control using only heater power, and eliminates the pull rate variability required by Cope to control diameter.

It is believed that a full and complete response has been made to the Office action and, as such, the application is in condition for allowance. Such allowance is hereby respectfully requested.

The Commissioner is hereby authorized to charge any fees that may be required during the entire pendency of this application to Deposit Account No. 19-1345.

Respectfully submitted,



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